TARDEC

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THE NATION'S LABORATORY FOR ADVANCED AUTOMOTIVE TECHNOLOGY

No. 13976

LAB TEST OF A PROTOTYPE HMMWV AIR FILTER ELEMENT CONSTRUCTED WITH MICROSTRUCTURED ORIENTED FIBER (MOF) FILTER MEDIA

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14. ABSTRACT

Two prototype Microstructured Oriented Fiber (MOF) air filter elements were designed and built to fit a HMMWV (M998 Utility Truck) multi-stage housing by MicroEnergy Technologies Inc. under contract DAAE07-03-C-L066. During April and May of 2003, the MOF filters underwent dust capacity and efficiency performance testing at the U.S.Army Tank Automotive Research, Development and Engineering Center (TARDEC). The MOF filter did not meet the efficiency or dust capacity performance requirements. The MOF filter attained an efficiency of 66.78%, which is far lower than the required 99.5%. The MOF filter achieved a dust capacity of 40 minutes, which is considerably less than the required 20 hours. During the efficiency and dust capacity testing, the pressure drop across the master (absolute) filter increased rapidly which indicated the MOF filter was allowing a significant amount of dust to pass through resulting in low performance. The MOF filter is not recommended for the M988 since the dust capacity and initial efficency did net meet the performance requirements.

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SUMMARY

This technical report, prepared by the Propulsion Product Support Team, under Contract DAAE07-03-C-L066, describes the dust capacity and efficiency testing performed on a new innovative air filter media at the Tank Automotive Research Development Engineering Center (TARDEC). A Small Business Innovative Research (SBIR) contractor designed and built an innovative air filter element to fit a M998 HMMWV multi-stage housing using their new filter media. The filter media is micromachined and made from an array of tiny perforated stainless steel pieces. The stainless steel pieces are called micropillars. The new stainless steel filter is called a Microstructured Oriented Fiber (MOF) filter.

The test results showed the MOF filter had a dust capacity of 40 minutes, which is considerably less than the required 20 hours. The pressure drop across the master filter increased rapidly which indicated a considerable amount of dust was going through the MOF filter media. The contractor was allowed to modify the MOF filter element design prior to efficiency testing.

After the modifications were completed, TARDEC conducted the efficiency test on the improved MOF filter element. The test results showed an initial efficiency of 66.78%, which is far lower than the required 99.5%. Once again, the pressure drop across the master filter increased rapidly indicating a considerable amount of dust leakage through the MOF filter media. Based upon the test results, using the Army's current test methods and procedures, the MOF filter is unacceptable for use on the M998 since the dust capacity and initial efficiency did not meet the performance requirements.

1.0 INTRODUCTION

Air filter elements must undergo performance testing before being considered for use on military vehicles. This technical report describes the performance test results and evaluation of the dust capacity and initial efficiency tests that were conducted by the U.S. Army Tank-Automotive Research, Development and Engineering Center (TARDEC) under Contract DAAE07-03-C-L066, on a prototype MOF filter media. The MOF filter media is micromachined and made from an array of minute perforated stainless steel pieces. The stainless steel pieces are in the shape of tiny rectangular pillars so are appropriately called micropillars.

In January 2003, a Phase I SBIR kick-off meeting was held at TARDEC where the Contractor claimed the MOF filter would out perform existing paper filters based on results from their Computational Fluid Dynamic (CFD) code and in-house testing. The contractor, MicroEnergy Technologies Inc. (MicroET), wanted to validate this claim through performance testing at TARDEC. Following the initial kickoff meeting, a no cost modification was made to contract DAAE07-03-C-L066 to include the delivery of two (2) prototype MOF air filters to TARDEC's Airflow Laboratories for performance testing. The Government would provide the Contractor with results of the Government testing.

The performance testing took place in April and May of 2003. Testing was conducted with the MOF filter element installed in a M998 HMMWV (P/N 19207-1233911) multi-stage housing and set up in Building 7 at TARDEC. Representatives from MicroET visited the TARDEC test facility to observe the testing.

2.0 OBJECTIVE

The objective of the test was to determine initial efficiency and dust capacity performance for the prototype MOF filter elements provided by MicroET. Testing was conducted in accordance with Military Specification MIL-PRF-46736E 21 August 1998.

3.0 CONCLUSIONS

Two prototype MOF filter elements were built and tested. The MOF filter elements did not meet the dust capacity or initial efficiency performance requirements. Testing the MOF filter at TARDEC provided the performance data necessary to evaluate the innovative filter media.

4.0 RECOMMENDATIONS

The MOF filter is not recommended for the M998 since the dust capacity and initial efficiency did not meet the performance requirements.

5.0 TEST MATERIAL

MOF Filter #1 (with prefilter) is shown in Figure 1 and was used for the first dust capacity test and cumulative efficiency test.

MOF Filter #1 (prefilter cut away) is shown in Figure 2 and was used for the second dust capacity and cumulative efficiency test.

MOF Filter # 2, (improved design), was used for the initial efficiency test. The improved filter design included reducing the size of the openings between the micropillars and electrically charging the filter element for enhanced efficiency.

Testing was conducted with the MOF filter element installed in a HMMWV (P/N 19207-1233911) multi-stage housing.

6.0 TEST EQUIPMENT AND PROCEDURE

The test equipment used included: (1) test bench no. 1, 1200 CFM; (2) AccuRate dust feeder; (3) nozzle size, 3 1/8 inch, 500 CFM and (4) piezometer tube 4 in diameter.

The test sequence was to measure initial restriction (pressure drop) as a function of airflow rate for each element, conduct initial efficiency test (MOF filter #2 only) and cumulative efficiency tests (MOF filter #1 with prefilter and MOF filter with prefilter cut away) while measuring dust capacity to 20 inches of water terminal pressure drop across the element and housing at rated airflow (see APPENDIX A).

7.0 RESULTS AND DISCUSSION

The test results are presented in Figures 3 and 4. Figure 3 displays the initial restriction, initial and cumulative efficiency and dust capacity. Figure 4 shows pressure drop as a function of dust fed to the MOF filter and HMMWV housing. Two dust capacity tests were conducted on MOF filter #1, one with a prefilter around the micropillar media and one with the prefilter around the mircropillar media cut away. The contractor cut away the prefilter around the micropillar media and attained an acceptable initial restriction on the second dust capacity test.

During the dust capacity and initial efficiency testing the pressure drop across the master filter increased rapidly (see Figure 4) which indicated a considerable amount of dust leakage was taking place. After the first dust capacity test, visual inspection showed leakage around the seals and through the MOF filter media. Seals were modified and no leaks were noticed during the second dust capacity or initial efficiency test. This indicated the MOF filter media design was allowing a significant amount of dust to leak through. The contractor was allowed to modify the MOF filter media design prior to initial efficiency testing. With the improved design, the MOF filter media was still allowing a significant amount of dust to pass through causing the testing to be terminated because the master (absolute) filter reached its pressure drop limit.

FIGURE 1. SIDE VIEW OF MOF FILTER #1 WITH PREFILTER

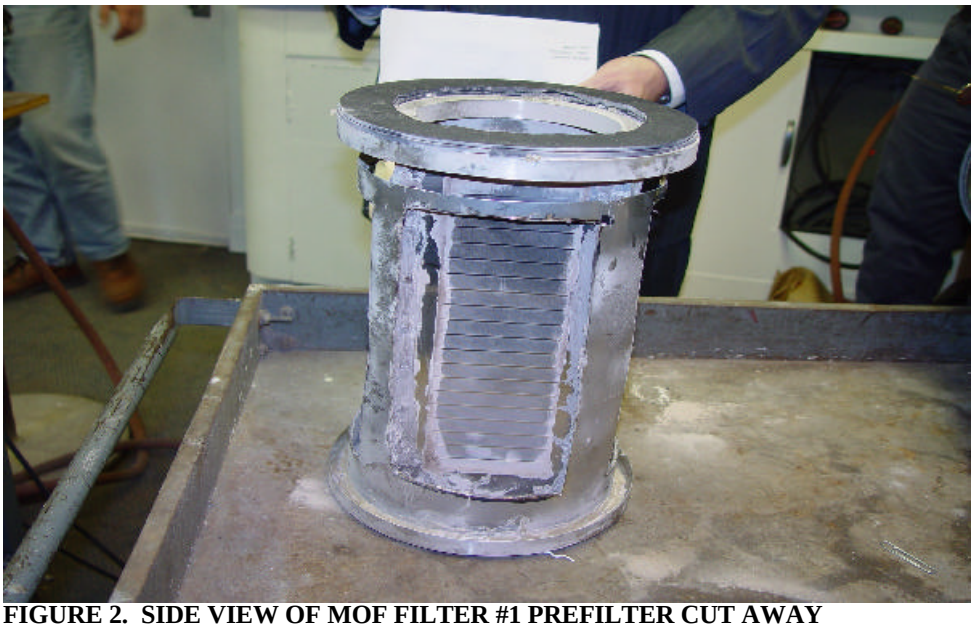

FIGURE 2. SIDE VIEW OF MOF FILTER #1 PREFILTER CUT AWAY

TEST	FILTER #1 w/Prefilter	FILTER #1 w/o Prefilter	FILTER #2 Improved design	REQUIRE-MENT	UNIT
INITIAL RESTRICTION	15.3	7.7	7.19	9	Inches of water
INITIAL EFFICIENCY** SAE fine dust @ rated airflow 420 scfm	N/A	N /A	66.78	99.5	%
DUST CAPACITY SAE Coarse dust variable airflow cycle	30 minutes	40 minutes	N/A	20 hours	
CUMULATIVE EFFICIENCY** SAE Coarse dust variable airflow cycle	85.6	87.17	N/A	99.9	%
COMMENTS	Dust leaking through seal and media	No seal leaks. Dust leaking through media	No seal leaks. Dust leaking through media.	N/A	

FIGURE 3 - MOF FILTER TEST RESULTS *

*The MOF filter was installed in a HMMWV (P/N 19207-1233911) multi-stage housing.

$$**\% \text{ Efficiency} = \left[1 - \frac{\text{wt. gain of absolute}}{\text{wt. of dust fed}}\right] \text{x } 100$$

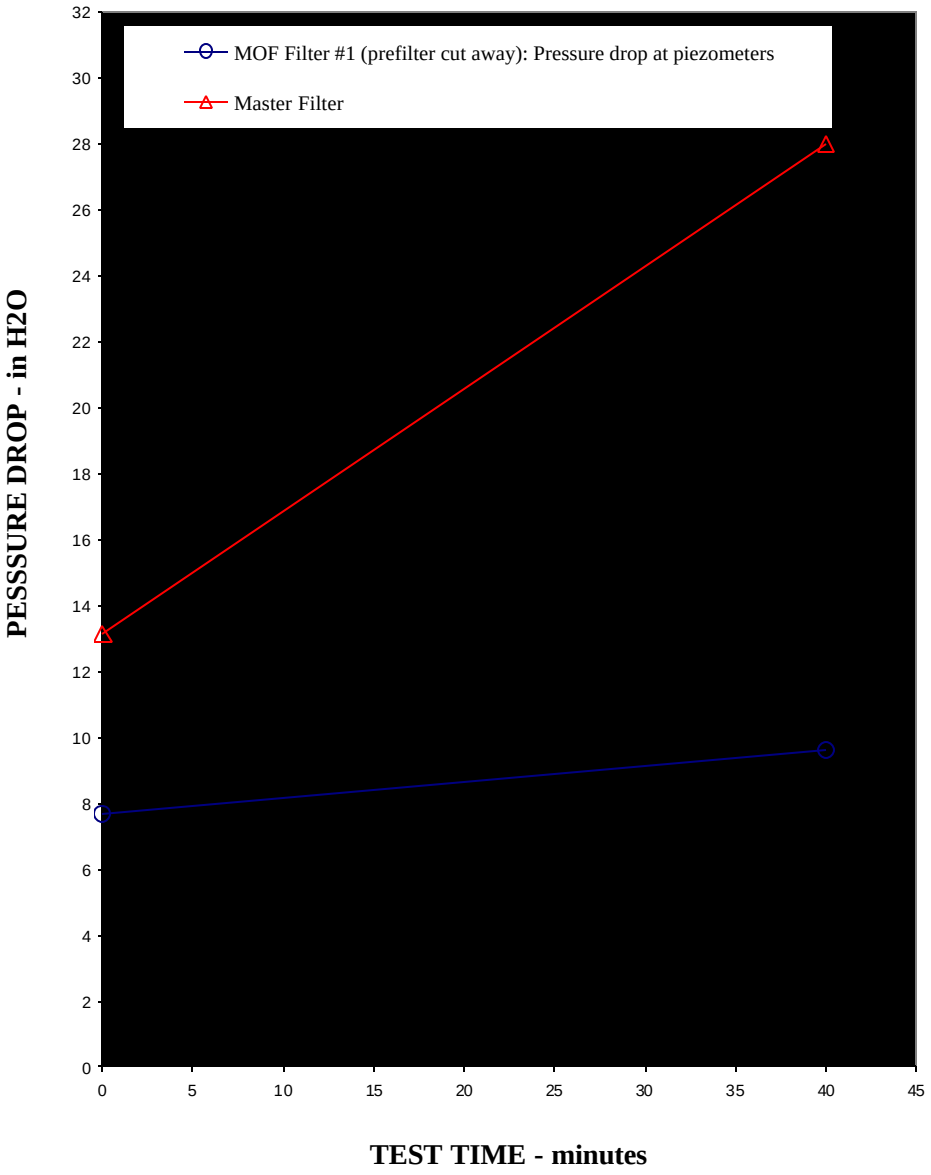

FIGURE 4. PRESSURE DROP VS AIRFLOW TEST TIME

APPENDIX A

MOF FILTER TEST PLAN

INTRODUCTION

This test plan details the scope of work, to be performed by TARDEC's Propulsion Products Support Team and Test Operations Team for Contract DAAE07-03-C-L066 to determine the efficiency and dust capacity of a prototype MOF filter made by MicroET. These tests will be conducted in Airflow Laboratory, Building 7

OBJECTIVE

The objective of this test is to evaluate the dust capacity and initial efficiency performance of a new filter media.

TEST MATERIAL

The air filter to be tested is known as a Microstructured Oriented Fiber (MOF) filter designed and built by MicroEnergy Technologies Inc. (MicroET). Two prototype air filters and a production air cleaner housing used for testing. MOF filter #1 will be used for the dust capacity testing. MOF filter #2 will be used for the initial efficiency testing. MicroET will provide the prototype MOF stainless steel air filters. TARDEC will provide the HMMWV (P/N 19207-1233911) multi-stage housing.

TEST CONDITIONS - Shall be in accordance with MIL-PRF-62048C Section 3.4

Ambient Temperature	70 to 90 ^{o}F
Relative Humidity	30 to 65%
Rated Air Flow	420 cfm @ standard atmospheric conditions of 760 mm of mercury (29.92" Hg) barometric pressure @ 27 ^{o}C (80 ^{o}F) ambient temperature providing an air density of 1.17 kg/m3 (0.073 lb/ft3)
Airflow Restriction Values	Shall be corrected to airflow with a density of 1.17 kg/m^3 and accurate to ± 0.025 kPa (0.1 inch water)
Test Dust	Fine and coarse dust per SAE J726 chemical analysis and particle size distribution.
Dust Feeding Rate	.883 g/m^3 (0.025 g/ft^3) ± 0.177 g/m^3 (0.005 g/ft^3)

TEST PROCEDURE

1. Install the HWWMV air cleaner on the test stand, shown in FIGURE A-1, in accordance with MIL-PRF-62048C APPENDIX A, FIGURE 2.

2. Instrument Test Stand.
   Pressure transducer across air cleaner: P 0–30 in H_2O ± 0.1
   Pressure transducer across master filter: P 0–30 in H_2O ± 0.1

3. Determine the following weight to an accuracy of 0.5 grams (electronic scale) before and after the test and anytime the scavenge dust collector jar is emptied:
   a. Dust Feeder and Inlet Conductors
   b. Air Cleaner without scavenge dust collector jar
   c. Scavenge dust collector jar
   d. Filter Element

4. Determine Master Filter Element weight to an accuracy of ±0.01 grams.

5. Determine and record initial airflow restriction at rated flow per MIL-PRF-62048C Section 4.5.3.2. The initial airflow restriction of the air cleaner shall not exceed 2.2 kPa (9 in H_2O) at rated airflow.

6. Determine initial efficiency per MIL-PRF-46736E Section 4.4.3. With the air adjusted to rated flow, fine grade dust shall be fed at 0.883 ±0.176 g/m3 air (0.025 gm/ft^3) until 110 grams of dust has been fed or until 30 minutes have been reached, which ever results in a greater quantity of dust. The initial efficiency shall not be less than 99.5 % using the following equation:

$$\% \text{ Efficiency} = \left[1 - \frac{\text{Wt. of master filter and entrapped dust - Original wt. of master filter}}{\text{Wt. of dust fed}} \right] \text{x } 100$$

7. Determine dust capacity per MIL-PRF-46736E Section 4.4.4
Feed coarse dust into the air cleaner at a rate of 0.025 gm/ft^3 without a dust injector nozzle.
   a. The test will be conducted at variable air flows and dust flow as follows:

Step	Duration (min)	Dust (gm/ft^3)	Airflow(ft^3/min)	Dust fed (grams)
1	10	0.025	420	105
2	10	0.025	252	63
3	10	0.025	84	21
4	10	0.025	336	84
5	10	0.025	252	63
6	10	0.025	168	42

   b. See Variable airflow cycle in FIGURE A-2 and use the 60-min. cycle, 10-min. intervals. This airflow cycle is from MIL-PRF-46736E Section 4.3.2.
   c. Record airflow restriction every ten minutes at beginning of each flow step.
   d. When the rated air flow (420 CFM) pressure drop is getting close to 20 inches of water, a rated air flow pressure drop reading will be taken at 30 minutes. Do this when the test will not last more then two or three hours longer.
   e. Testing will stop when the air cleaner airflow restriction reaches 20 inches of water at the rated airflow of 420 CFM.

8. Determine and record post-service airflow restriction at rated flow per MIL-PRF-46736E Section 3.3.5 & Section 4.4.5. The air cleaner shall not exceed its original restriction by more than 249 Pa (1 inch H_2O) at rated airflow after cleaning.

9. Determine cumulative efficiency in reference to the dust capacity test per MIL-PRF-46736E Section 4.4.4 and dust collection efficiency shall be not less than 99.9%.

FIGURE A-1. AIR CLEANER TEST SET UP

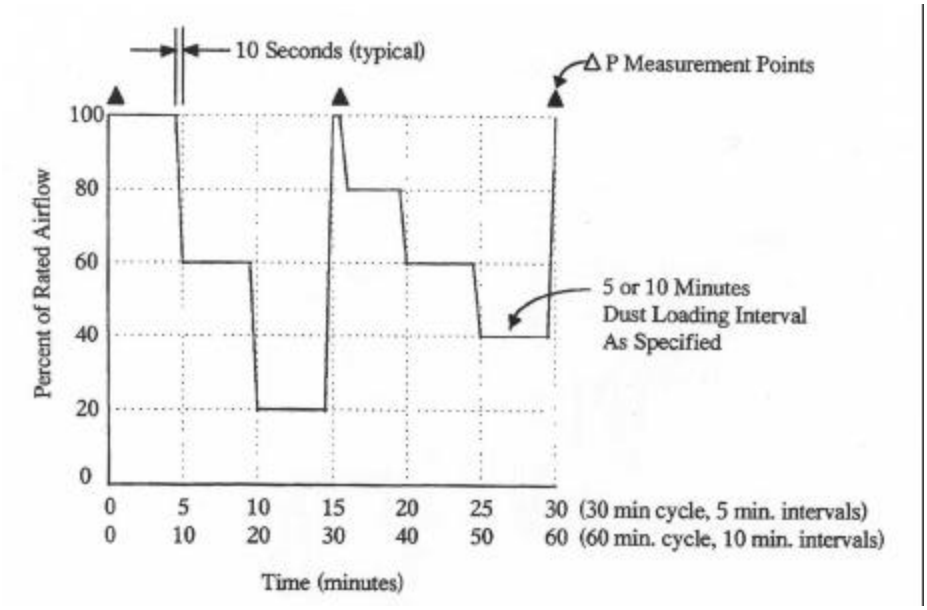

FIGURE A-2. VARIABLE AIRFLOW CYCLE

APPENDIX B

MOF FILTER TEST DATA

DUST CAPACITY TEST - MOF FILTER #1 WITH PREFILTER 04-29-03

Dust capacity = 30 minutes.

% Cumulative Efficiency = 85.6%

$$\%\,\text{Cumulative Eff.} = \left[1 - \frac{\text{Wt. of master filter \& entrapped dust} - \text{Original wt. of master filter}}{\text{Wt. of dust fed}}\right] \text{x } 100$$

Wt. of master filter & entrapped dust = 130 grams
Original wt. of master filter = 103 grams
Wt. of Dust fed = 191 + (-4) = 187 grams

The test was terminated when the master filter reached it pressure drop limit.

Components	Original Wt. (grams)	Original Wt. & Entrapped Dust (grams)	Difference
Dust feeder, Dust, Dust Tray	36134	35943	191
Dust delivery hose, Inlet piezometer tube, smooth approach nozzle, hose & clamp	6230	6234	-4
Master filter	103	130	27

DUST CAPACITY TEST DATA

Time (min	Airflow (SCFM)	Pressure drop across Air Cleaner ("H2O)	Pressure drop across Master Filter ("H2O)
0	413.6	15.30	12.15
10	255.3	6.88	7.95
20	75.0	1.00	2.14
30	412.3	24.48	19.22

DUST CAPACITY TEST - MOF FILTER #1 PREFILTER CUT AWAY 04-29-03

Dust capacity = 40 minutes

% Cumulative Efficiency = 87.17%

$$\% \text{ Cumulative Eff.} = \left[1 - \frac{\text{Wt. of master filter \& entrapped dust} - \text{Original wt. of master filter}}{\text{Wt. of dust fed}}\right] \text{x } 100$$

Wt. of master filter & entrapped dust = 133.33 grams
Original wt. of master filter = 102.85 grams
Wt. of Dust fed = 240 + (-2.5) = 237.5 grams

The test was terminated when the master filter reached it pressure drop limit.

Components	Original Wt. (grams)	Original Wt. & Entrapped Dust (grams)	Difference
Dust feeder, Dust, Dust Tray	35927	35687	240
Dust delivery hose, Inlet piezometer tube, smooth approach nozzle, hose & clamp	6231	6234	-2.5
Master filter	102.85	133.33	30.48

DUST CAPACITY TEST DATA

Time (min)	Airflow (SCFM)	Pressure Drop across Air cleaner ("H2O)	Pressure Drop across Master Filter ("H2O)
0	417.8	7.70	13.13
10	252.0	3.00	9.00
20	72.4	0.44	2.57
30	336.0	6.00	16.50
40	420.0	9.60	28.00

INITIAL EFFICIENCY TEST - MOF FILTER #2 05-20-03

% Initial Efficiency = 66.78%

$$\% \text{ Initial Efficiency} = \left[1 - \frac{\text{Wt. of master filter and entrapped dust} - \text{Original wt. of master filter}}{\text{Wt. of dust fed}}\right] \text{x } 100$$

Wt. of master filter & entrapped dust = 254.4 grams
Original wt. of master filter = 197.1 grams
Wt. of dust fed = 191.5 + (-19) = 172.5 grams

The test was terminated when the master filter reached it pressure drop limit.

Components	Original Wt. (grams)	Original Wt. & Entrapped Dust (grams)	Diff. (grams)
Dust feeder, Dust, Dust Tray	31743.5	31552	191.5
Dust delivery hose, Inlet piezometer tube, smooth approach nozzle, hose & clamp	6232	6251	-19
Master filter	197.1	254.4	54.3

EFFICIENCY TEST DATA

Time	Airflow SCFM	Pressure Drop across Air cleaner ("H_2O)	Pressure Drop across Master Filter #1("H_20)	Pressure Drop across Master Filter #2("H_2O)
0	417.6	7.19	12.0	
1	420.9	7.37	12.0	
2	416.1	7.28	12.3	
3	413.4	7.79	13.1	
4	413.6	8.16	12.7	
5	414.8	8.92	13.1	12.2
6	417.6	9.42		12.3
7	416.1	10.15		12.4
8	415.8	10.90		13.1
9	419.0	11.61		13.2
10	413.2	11.92		13.9
11	416.8	12.02		15.5
12	417.9	12.03		15.9
13	416.1	12.22		16.5
14	414.3	12.70		17.1
15	412.3	12.99		17.7
16	412.0	13.35		19.3
17	405.6	13.53		22.8